Splitting the Reference Time: Temporal Anaphora and Quantification in DRT

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Abstract

This paper presents an analysis of temporal anaphora in sentences which contain quantification over events, within the framework of Discourse Representation Theory. The analysis in (Partee, 1984) of quantified sentences, introduced by a temporal connective, gives the wrong truth-conditions when the temporal connective in the subordinate clause is *before* or *after*. This problem has been previously analyzed in (de Swart, 1991) as an instance of the *proportion problem*, and given a solution from a Generalized Quantifier approach. By using a careful distinction between the different notions of *reference time*, based on (Kamp and Reyle, 1993), we propose a solution to this problem, within the framework of DRT. We show some applications of this solution to additional temporal anaphora phenomena in quantified sentences.

1 Introduction

The analysis of temporal expressions in natural language discourse provides a challenge for contemporary semantic theories. (Partee, 1973) introduced the notion of *temporal anaphora*, to account for ways in which temporal expressions depend on surrounding elements in the discourse for their semantic contribution to the discourse. In this paper, we discuss the interaction of temporal anaphora and quantification over eventualities. Such interaction, while interesting in its own right, is also a good test-bed for theories of the semantic interpretation of temporal expressions. We discuss cases such as:

(1) *Before* John makes a phone call, he *always* lights up a cigarette. (Partee, 1984)

(2) *Often, when* Anne came home late, Paul had already prepared dinner. (de Swart, 1991)

(3) *When* he came home, he *always* switched on the tv. He took a beer and sat down in his armchair to forget the day. (de Swart, 1991)

(4) *When* John is at the beach, he *always* squints *when* the sun is shining. (de Swart, 1991)

The analysis of sentences such as (1) in (Partee, 1984), within the framework of *Discourse Representation Theory* (DRT) (Kamp, 1981) gives the wrong truth-conditions, when the temporal connective in the sentence is *before* or *after*. In DRT, such sentences trigger box-splitting with the eventuality of the subordinate clause and an updated reference time in the antecedent box, and the eventuality of the main clause in the consequent box, causing undesirable universal quantification over the reference time.

This problem is analyzed in (de Swart, 1991) as an instance of the *proportion problem* and given a solution from a Generalized Quantifier approach. We were led to seek a solution for this problem *within* DRT, because of DRT's advantages as a general theory of discourse, and its choice as the underlying formalism in another research project of ours, which deals with sentences such as 1–4, in the context of natural language specifications of computerized systems. In this paper, we propose such a solution, based on a careful distinction between different roles of Reichenbach's *reference time* (Reichenbach, 1947), adapted from (Kamp and Reyle, 1993). Figure 1 shows a 'minimal pair' of DRS's for sentence 1, one according to Partee's(1984) analysis and one according to ours.

2 Background

An analysis of the mechanism of temporal anaphoric reference hinges upon an understanding of the ontological and logical foundations of temporal reference.

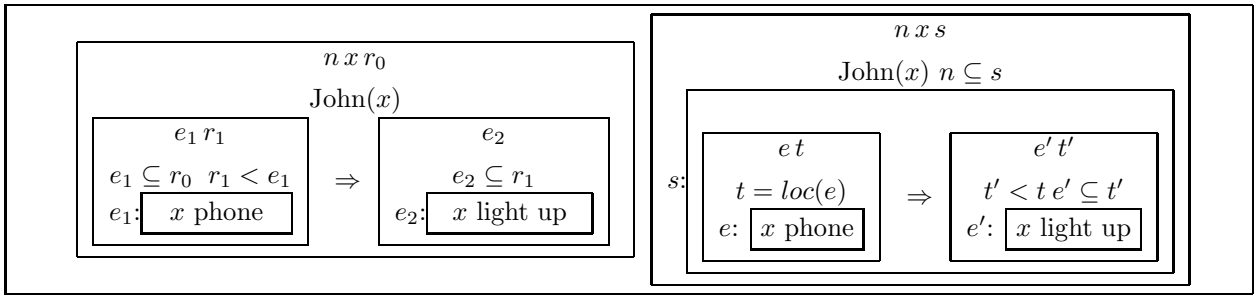

Figure 1: a:Partee's analysis b:Our analysis

Different concepts have been used in the literature as primitives. These range from temporal instants in *Tense logic* (Prior, 67), through intervals of time (Bennet and Partee, 1978(1972)) as in the analysis of temporal connectives in (Heinämäki, 1978), to event structures (Kamp, 1979) as in Hinrichs' (1986) analysis of temporal anaphora.

An important factor in the interpretation of temporal expressions is the classification of situations into different aspectual classes (or Aktionsarten), which is based on distributional and semantic properties. In this paper, we only consider *events* and *states*, together termed *eventualities* in (Bach, 1981). In narrative sequences, event clauses seem to advance the narrative time, while states block its progression. The mechanism used to account for this phenomena in (Hinrichs, 1986) and (Partee, 1984), is based on the notion of *reference time*, originally proposed by Reichenbach (1947).

Reichenbach's well - known account of the interpretation of the different tense forms uses the temporal relations between three temporal indices: the *utterance time*, *event time* and *reference time*. The reference time according to (Reichenbach, 1947) is determined either by context, or by temporal adverbials.

2.1 A unified analysis of temporal anaphora

Hinrichs' and Partee's use of a notion of reference time, provides for a unified treatment of temporal anaphoric relations in discourse, which include narrative progression especially in sequences of simple past tense sentences, temporal adverbs and temporal adverbial clauses, introduced by a temporal connective. This concept of reference time is no longer an instant of time, but rather, an interval. This approach can be summarized as follows: in the processing of a discourse, the discourse-initial sentence is argued to require some contextually determined reference time. Further event clauses in the discourse introduce a new event, which is included within the then-current reference time. Each such event also causes the reference time to be updated to a time 'just after' (Partee, 1984) this event. State clauses introduce new states, which include the current reference time, and do not update it.

As an example of such an analysis consider the following narrative discourse (Partee, 1984):

(5) John got up, went to the window, and raised the blind. It was light out. He pulled the blind down and went back to bed. He wasn't ready to face the day. He was too depressed.

Figure 2 shows a DRS for the first two sentences of this discourse, according to Hinrichs' and Partee's analysis. The 'n' in the top DRS is a mnemonic for 'now'- the utterance time. The first event in the discourse, e_1 – John's getting up – is interpreted relative to a contextually understood reference time, r_0. The event e_1 is included in the current reference time, r_0. A new reference time marker, r_1 is then introduced. r_1 lies immediately after r_0 (recorded as $r_0 \preceq r_1$). r_1 serves as the current reference time for the following event e_2. We continue in this fashion, updating the reference time, until the second sentence in the discourse is processed. This sentence denotes a state, s_1, which includes the then-current reference time.

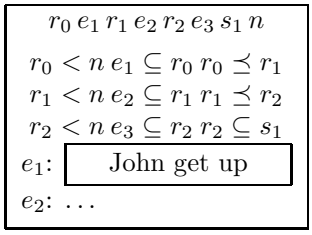

Figure 2:

Adverbial phrases, whether phrasal (e.g. 'On Sunday') or clausal (e.g. 'When Bill left'), are processed before the main clause. They introduce a reference time, which overrides the current reference time, and

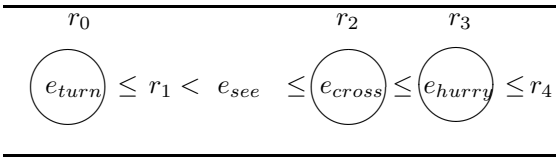

Figure 3:

provides an anaphoric antecedent for the tense in the main clause. This mechanism is used to explain how tense and temporal adverbials can combine to temporally locate the occurrence, without running into problems of relative scope (Hinrichs, 1988). The tense morpheme of the main clause locates the event time with respect to the reference time, whereas temporal adverbials are used to locate the reference time.

When-clauses, for example, introduce a new reference time, which is ordered after the events described in the preceding discourse. The eventuality in the *when*-clause is related to this reference time as discussed earlier with respect to narrative progression: a state includes its reference time, while an event is included in it. The eventuality in the main clause is interpreted with respect to this reference time. If the main clause is an event-clause, this event introduces a new reference time, just after the event time of the main clause. As an example, consider the following discourse (Partee, 1984):

(6) Mary turned the corner. When John saw her, she crossed the street. She hurried into a store.

Following Partee (1984), we will not construct a full DRS for this discourse, but illustrate it with a diagram in Figure 3, with circles denoting inclusion.

2.2 Quantification over events

(Partee, 1984) extends Hinrichs' treatment of temporal anaphora to the analysis of sentences, which contain a temporal adverbial and quantification over eventualities. According to her analysis, these trigger box-splitting as do *if* or *every* clauses in DRT (Kamp, 1981). Consider the following example from (Partee, 1984):

(7) Whenever Mary telephoned, Sam was asleep.

The subordinate clause cannot be interpreted relative to a single reference time, since Mary's telephoning is not specified to occur at some specific time. Still, the sentence needs to be interpreted relative to a reference time. This reference time can be a large interval, and should contain each of the relevant occurrences of Mary's telephoning during which

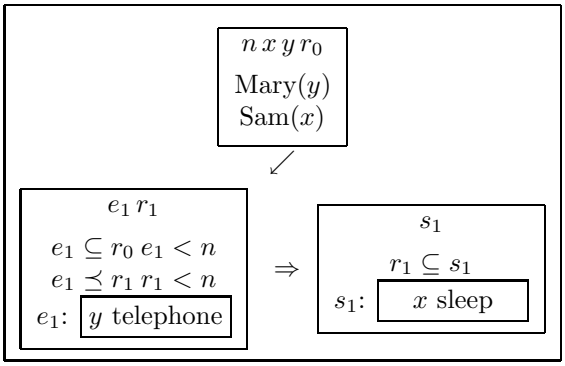

Figure 4:

Bill was asleep. This reference time is represented as r_0 in the top sub-DRS.

The *'whenever'* triggers box-splitting. The event marker - e_1 is introduced in the antecedent box, with the condition that it be temporally included in the current reference time, r_0 and be prior to n. The *'whenever'* also causes the introduction of r_1, a new reference time marker. r_1 lies 'just after' e_1. The stative clause causes the introduction of s_1, which includes the reference time r_1.

The embedding conditions for the whole construction are just like those for a regular *'if'* or *'every'* clause, i.e. the sentence is true, if every proper embedding of the antecedent box can be extended to a proper embedding of the combination of the antecedent and the consequent boxes. This means, as desired, that for each choice of an event e_1 of Mary's telephoning, and reference time r_1 'just after' it, there is a state of Sam's being asleep, that surrounds r_1.

A sentence such as (7a) which is the same as sentence 7, except the *'whenever'* is replaced by *'when'*, and *'always'* is added in the main clause, would get the same DRS.

(7a) When Mary telephoned, Sam was always asleep.

2.3 Extending the analysis

As noted in (Partee, 1984), this analysis does not extend in a straightforward manner to cases in which the operator *when* is replaced by (an unrestricted) *before* or *after*, in such quantified contexts. Constructing a similar DRS for such sentences gives the wrong truth conditions. For example, Figure 1a shows a DRS for sentence 1, according to the principles above. r_1 - the reference time, used for the interpretation of the main clause is placed in the universe of the antecedent box. Because the temporal connective is 'before', r_1 is restricted to lie before e_1. The embedding conditions determine, that this

reference time be universally quantified over, causing an erroneous reading in which for each event, e_1, of John's calling, for each earlier time r_1, he lights up a cigarette. Paraphrasing this, we could say that John lights up cigarettes at all times preceding each phone call, not just once preceding each phone call. We did not encounter this problem in the DRS in Figure 4, since although the reference time r_1, is universally quantified over in that DRS as well, it is also restricted, to immediately follow e_1. It is similarly restricted if 'before' is replaced with 'just before' or 'ten minutes before'. But, (unrestricted) 'before' is analyzed as 'some time before', and thus the problem arises. We will henceforth informally refer to this problem as Partee's quantification problem.

Partee (1984) suggests that in these cases we somehow have to insure that the reference time, r_1, appears in the universe of the consequent DRS, causing it to be existentially quantified over, giving the desired interpretation. De Swart (1991) notes that simply moving r_1 to the right-hand box does not agree with Hinrichs' assumption, that temporal clauses are processed before the main clause, since they update the reference time, with respect to which the main clause will be interpreted. In our proposed solution, the 'reference time' is indeed moved to the right box, but it is a different notion of reference time, and (as will be shown) exempt from this criticism.

3 The proportion problem

De Swart (1991) sees Partee's quantification problem as a temporal manifestation of the *proportion problem*, which arises in cases such as (Kadmon, 1990):

(8) Most women who own a cat are happy.

The sentence is false in the case where out of ten women, one owns 50 cats and is happy, while the other nine women own only one cat each, and are miserable. This will not be predicted by the unselective binding of quantifiers in DRT, which quantify over all the free variables in their scope, in this case women-cat pairs. According to (de Swart, 1991) Partee's quantification problem is similar - the universal quantifier in sentences such as (1) binds pairs of events and updated reference times, where the desired quantificational scheme is universal quantification for the event and existential for the reference time.

De Swart (1991) offers a solution from a Generalized Quantifier approach, based on the analysis of quantified NPs in transitive sentences. In this analysis, the reference time is an implicit variable, which is needed in the interpretation of the temporal relation, but is not part of the quantificational structure.

Temporal connectives are viewed as relations, TC, between two sets of events:

(9) $\{< e_1, e_2 > | < e_1, e_2 > \in TC\}$

The quantificational structure of such sentences can be analyzed either by an iteration of monadic quantifiers, or as a single dyadic quantifier of type $< 1, 1, 2 >$. In the first approach, adverbs of quantification (Q-adverbs) are assigned the structure:

(10) $Q(S_s, \{e_1 | \exists(S_m, TC_{e_1})\})$

In 10, S_s and S_m denote, respectively, the sets of events described by the subordinate and the main clause, TC_{e_1} denotes the image set of e_1 under the temporal connective TC, i.e. the set of events e_2 which are related to e_1 via the relation TC, (presented in 9). In the second approach, the structure is:

(11) $[Q, \exists](S_s, S_m, TC)$

De Swart's solution does overcome Partee's quantification problem, although not within DRT. As such, the existential quantification in 11 has to be stipulated, whereas our analysis acquires this existential quantification 'for free'.

4 Splitting the role of reference time

Our analysis of Partee's quantification problem uses a different notion of reference time than that used by the accounts in the exposition above. Following (Kamp and Reyle, 1993), we split the role of the reference time, used to account for a large array of phenomena, into several independent mechanisms. This separation allows for an analysis in DRT of temporal subordinate clauses in quantified sentences, which avoids Partee's problem altogether. The mechanisms we discuss are: the **location time**, **Rpt** and **perf**[1]. DRSs will contain temporal markers corresponding to location times and Rpts.

The location time is an interval, used to temporally locate eventualities, in accordance with their aspectual classification. Events are included in their location time (recorded in the DRS as $e \subseteq t$ on the respective markers), while states temporally overlap their location time (recorded as $s \bigcirc t$). The verb tense determines the relation between the location time and the utterance time e.g. if the tense is simple

[1] An additional mechanism is the **TPpt**, which for simplicity's sake will not be discussed in this paper.

past, the location time lies anteriorly to the utterance time. When it is simple present, the location time coincides with the utterance time[2]. Temporal adverbials restrict the location time: temporal adverbs introduce a DRS-condition on the location time, while temporal subordinate clauses introduce a relation between the event time[3] of the subordinate clause and the location time of the main clause. The exact temporal relation denoted by a temporal connective depends on the aspectual classes of the eventualities related by it[4]. For example, in the following sentence 12, the event triggers the introduction of an event marker e, and location time marker t, into the DRS with the DRS-condition $e \subseteq t$. The past tense of the verb adds the condition $t < n$. In sentence 13, the location time of the event in the main clause is restricted to fall (just) after the event time of the event of the subordinate clause.

(12) Mary wrote the letter.

(13) Mary wrote the letter when Bill left.

Narrative progression is dealt with by using the feature Rpt (or reference point). The Rpt can be either an event or a time discourse marker, already present in the DRS (recorded as assignment $Rpt := e$). Eventualities are interpreted with respect to the Rpt - events are taken to follow the current Rpt, while states include it. The Rpt is reset during the processing of the discourse. Note that in a 'terminal' DRS (ready for an embedding test), all the auxiliary Rpts 'disappear' (do not participate in the embedding).

The perfect is analyzed by using the notion of a *nucleus* (Moens and Steedman, 1988) to account for the inner structure of an eventuality. A nucleus is defined as a structure containing a *preparatory process*, *culmination* and *consequent state*. The categorization of verb phrases into different aspectual classes can be phrased in terms of which part of the nucleus they refer to. The perfect is seen in (Kamp and Reyle, 1993) as an aspectual operator. The eventualities described by the perfect of a verb refer to the consequent state of its nucleus. For example, the following sentence 14 denotes the state, s, holding at the present, that Mary has met the president. This state is a result of the event e, in which Mary met the president. Temporally, the state s starts just when e ends, or as it is put in (Kamp and Reyle, 1993):e and s *abut*, (represented as $e \supset\subset s$).

(14) Mary *has met* the president.

5 An alternative solution

By extending the analysis of temporal subordinate clauses in (Kamp and Reyle, 1993), to sentences which include quantification over eventualities, we can propose an alternative DRT solution to Partee's quantification problem. As in (Partee, 1984), such sentences trigger box-splitting. But now, the location time of the eventuality in the subordinate clause serves as the antecedent for the location time of the eventuality in the main clause. In this approach, each of the relevant temporal markers resides in its appropriate box, yielding the correct quantificational structure. This quantification structure does not need to be stipulated as part of the Q-adverb's meaning, but arises directly from the temporal system. We illustrate this analysis by constructing a DRS in Figure 1b for sentence 1.

In this DRS, n denotes the utterance time. The subordinate clause triggers the introduction of an event marker, e, with its event time marker t. The main clause triggers the introduction of an event marker e', and its location time marker t', with the DRS-condition $e' \subseteq t'$. The assymetry in using the event time for e and the location time for e' arises from the interpretation rules of temporal connectives (for both quantified and non-quantified sentences). Since the temporal connective in this sentence is *before*, the relation between these two markers is one of precedence.

We adopt a suggestion by Chierchia in (Partee, 1984), that the whole implication be rendered as a state. This state is no longer an atomic eventuality. It is a complex state denoting John's habit. This state holds during the present, and so its location time is n.

This solution is not prone to de Swart's (1991) criticism against the naive solution of moving the reference time to the right DRS. The temporal clause may be processed before the main clause, since t', the location time of e', which 'replaces' r_1, the reference time of Partee's analysis, as the temporal index of the eventuality in the the main clause, arises from processing the main clause (not updating the reference time of the subordinate clause).

[2]Since the utterance time, n is a point in (Kamp and Reyle, 1993), the overlap relation between a state that holds in the present and n reduces to inclusion.

[3]The event time t of an eventuality e is the smallest interval which includes e (recorded as $t = loc(e)$).

[4]For the sake of the current presentation, we assume the following relations for *When*: if both the *when*-clause and the main clause denote states, then their respective time indices overlap. If both are events then the times are temporally close, with the exact relation undetermined. When one is a state and one an event, then the time index of the state includes that of the event cf. (Hinrichs, 1986).

6 Additional phenomena

In this section we present some applications of our analysis to related constructions. First, we consider the past perfect, as in sentence 2. De Swart (1991) gives this example to illustrate the inability to interpret temporal connectives without the use of the reference times. According to (de Swart, 1991), the subordinate clause determines the reference time of the verb, which lies anteriorly to the event time. Trying to use the event times would give the wrong analysis. This would seem to be troublesome for our approach, which uses the location time of the event in the main clause, and not its reference time. However, this is not a problem, since our analysis of the perfect by the use of the operator **perf**, analyses the eventuality referred to by the main clause, as the result state of a previous event. The temporal relation in the sentence is inclusion between the event time of Anne's coming home, and the location time of the result state of Paul's already having prepared dinner.

Next, we consider narrative progression in quantified contexts, as in sentence 3. The basic construction is just the same as in the paradigm structure, but now we have narrative progression in the consequent box. This narrative progression is handled as ordinary narrative progression in (Kamp and Reyle, 1993), i.e. by resetting the Rpt. The DRS in Figure 5 describes the complex state s_1, that after each event of John's coming home, there is a sequence of subsequent events according to his activities.

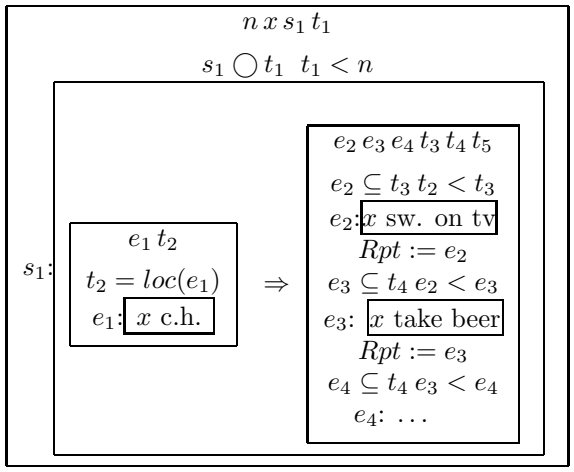

Figure 5:

Finally, we deal with sentences such as (4), which contain an iteration of an implicit generic quantifier and *always*. The situation described by John's always squinting when the sun is shining is analyzed as a complex state s_3. This state holds whenever John is at the beach, recorded by the condition that the location time t_2 of s_3 overlaps the event time, t_1 of John's being at the beach, s_2 in Figure 6.

7 Acknowledgments

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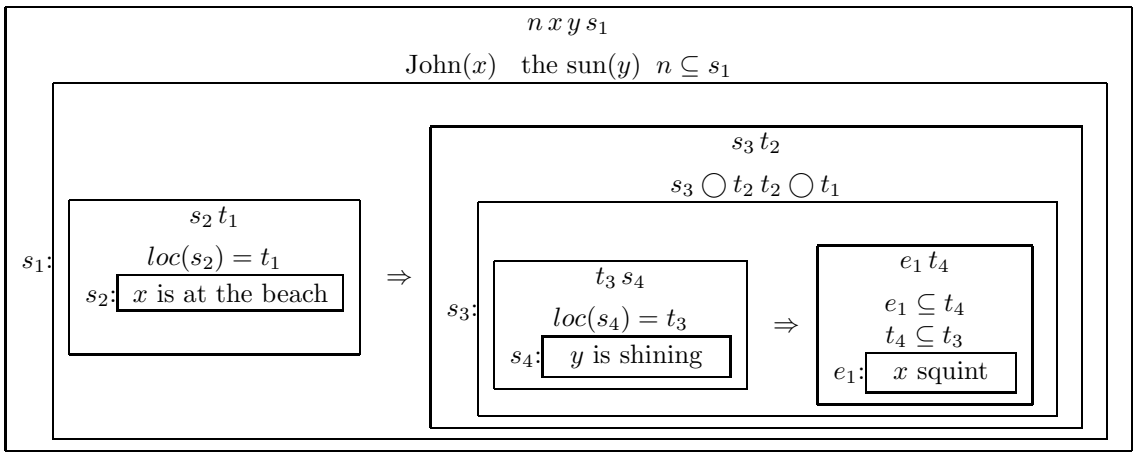

Figure 6:

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